BOTANICAL COMPOSITION AND MULTIVARIATE ANALYSIS OF VEGETATION ON THE POTHOWAR PLATEAU, PAKISTAN

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ABSTRACT

Vegetation of Pothowar Plateau (32° 32' and 34° north latitude and 70° 17' and 73° 5' east longitude, annual rainfall 250 to 750 mm) was analyzed using ordination (DECORANA) and classificatory cluster analysis techniques. Five plant associations were recognized on the basis of the cluster analysis. The most noticeable feature indicated by this analyses was the separation of mountain-complex communities from the flat lowland community. Clearly disjunct patterns emerged from these analyses. The major axes brought out by the ordination were related to broad soil types. The application of the classification to the ordination allowed an interpretation of the vegetation variation in terms of topography, redistribution of rainwater, the nature of the bedrock and soil depth. The vegetation patterns revealed are discussed in relation to geo-morphological factors and problems of plant assemblage in vegetation of widely scattered plants.

Key Words: Vegetation analysis, plant communities, Pothowar Plateau, Pakistan

RESUMEN

La vegetación de la meseta de Pothowar (32° 32' y 34° latitud Norte 70° 17' y 73° 5' longitud Este, precipitación anual de 250 a 750 mm) se analizó mediante ordenación (DECORANA) y técnicas clasificatorias de análisis cluster. Se reconocieron cinco asociaciones de plantas en base al análisis cluster. La característica más notable señalada por este análisis fue la separación del complejo de comunidades de montaña de la comunidad de las zonas llanas bajas. De los análisis surgieron patrones claramente disyuntos. Los ejes principales que salen de la ordenación están relacionados con los grandes tipos de suelo. La aplicación de la clasificación a la ordenación permitió una interpretación de la variación de la vegetación en términos de topografía, redistribución de la precipitación, la naturaleza de la roca madre y la profundidad del suelo. Se discuten los patrones de vegetación en relación con los factores geo-morfológicos y problemas de inserción de plantas muy diseminadas en la vegetación.

INTRODUCTION

Studies on the arid and semi-arid areas of Pakistan and India have mainly been floristical and/or phytogeographical (Athar 2005; Champion & Sethi 1968; Chaudhuri 1960; Hussain 1969; Gupta 1975; Shaukat et al. 1976; Malik et al. 1988). The use of numerical approaches has been rare (Shaukat et al. 1990; Shaukat & Ahmad 1989), although these may be useful for summarizing the major gradients in data sets, assisting the formulation of hypotheses and testing their validity (Birks 1992; Odgaard & Rasmussen 2000). Modern synecological methods have developed techniques for use at local and regional level, seeking to reduce the complexity of field data sets by classification and ordination of floristic data and then relating the results to environmental information (ter Braak 1987). Such objective approaches have rarely been applied to the vegetation data of Pakistan.

The primary objective of this study was to explore the factors that determine the boundaries and composition of plant communities on the Pothowar Plateau. This was achieved by sampling all common species present within a complex vegetation mosaic coinciding with local gradients in topography and soil distribution. Numerical techniques were used to summarize the floristic data.

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MATERIALS AND METHODS

Study Area

The Pothowar Plateau is situated between 32° 32' and 34° north latitude and 70° 17' and 73° 5' east longitude. It covers an extensive area of 1.5 million hectares. In altitude it rises from about 250 m near the Indus River to 1,076 m in the west. The hills are detached and isolated from each other. They run mostly in an east west direction and consist of a series of serrated ridges. The slopes are gentle at first and then climb more steeply. The steepness of the slopes varies from 15° to 50° and is precipitous in some places. Elsewhere the gradient is flat to gently undulating. It runs across the northern part of the area as a wedge with its base resting the Indus, where it is 22 km wide. It tapers gradually over a length of 72 km to the east, and ends about 24 km north-west of Margalla Range.

Climate

The climate of the area is of an extreme nature. The western portion of tract is hotter and drier than the eastern and northern parts. The winter is bitterly cold while the summer is unbearably hot. The temperature rises first in April, than remains almost steady, due to windstorms from Balochistan, up to the middle of May when it shoots up again. June and July are the hottest months (average maximum temperature 42° C), while December and January are the coldest months (average minimum temperature 1.7° C). The monsoon starts by the third week of July and continues till the beginning of September when the nights get cooler. The cold weather sets in by the middle of October. During winter the days are bright, and the nights are clear. Early spring frosts are common and sufficiently severe to cause wide spread injury to plants, even to the indigenous tree growth in a fairly advanced stage of development. Preliminary analyses of weather data indicate that mean temperature decreases in a linear fashion with altitude (Champion et al. 1965). Frost may occur especially at the upper altitudinal limits and in valley bottoms.

Rainfall is scanty and uncertain, and its annual distribution is very uneven. The annual rainfall varies from 250 to 750 mm. Monsoons start late in July, and most of the annual rain is before September. Spring and fall rains are rare and uncertain. Winter rains start by the end of December. They stop by the end of February when the windstorms set in. Winter rains generally extend over a shorter period than the monsoons, followed by a prolonged period of dry weather. Humidity is also generally low, falling to about 15% in the summer afternoons, the annual mean being about 50% (Hussain & Ilahi 1991).

The ground water resources are limited. The sources of water for humans and livestock are wells and dugout ponds. The drainage is very satisfactory. The entire area is drained off to the west into the Indus River, largely through Soan River. Springs are mostly seasonal and flow only during the rains. Perennial springs are very few, and are found at only 14 places.

Geology, soils and topography

Geologically the area is divisible into Attock slate and limestone. Attock slates are Precambrian and contain gritty layers of an arenaceous type. On weathering they give rise to fertile loamy clay, which collects only in sheltered places. The major part of the area (Kala-Chitta forest area) is composed of limestone in age from Triassic to Liassic. It contains marls, ferruginous and bleached shales and sandstones belonging to the Eocene suit, ferruginous pisolite, variegated sandstone, soft sandy carbonaceous clays, and shales varying in age from Albian to Tithorian. Tertiary freshwater formations of sandstone, alternating with red and purple clays and shales, are also very common in the Pothowar Plateau. Soils are universally shallow and dry and may overlie a great variety of geological formations from limestone, shales and quartzites to crystalline rocks. The soil derived from sandstone is poor and less fertile than soil from limestone. It supports nothing except the most xerophyllous vegetation (Hussain & Ilahi 1991)

Vegetation

Champion et al. (1965) described the study area as dry sub-tropical broad-leaved forest. Rafi (1973), Beg (1975), and Hussain and Ilahi (1991) called it dry sub-tropical semi-evergreen forest. The trees and shrubs are mostly thorny and have leaves of moderate size resembling Mediterranean vegetation elsewhere in the world (Naqvi 1974). There is usually little ground-layer vegetation most of the year, but during the monsoon a fairly complete cover of grass and herbs may develop. Floristic composition varies continuously in response to small-scale altitudinal differences on the plateau, although most species show fairly broad distribution patterns at that scale. The limestone region has only scrub forest composed of odd stunted and mutilated *Acacia* with its associates. A few diminutive *Olea* and *Rhamnus* can also be observed on the northern slopes. The southern slopes are almost entirely devoid of tree growth. The shrubs include a great many genera and families, many of central Asian origin. Unpalatable species are favored by heavy grazing, and *Dodonaea*, *Rhazya,* and *Withania* become conspicuous with thorny *Carissa* and *Gymnosporia*.

Pothowar Plateau is especially interesting because its vegetation merges at lower elevations with tropical thorn forests and at higher elevations with subtropical pine and temperate forests. Because of its elevation, precipitation on the plateau can reach, or even some times exceed, 600 mm, thus making Pothowar a sort of enclave of the fringes of the arid areas in which the diversity of natural sites (wooded wadies, humid canyons, springs and rock pools) has allowed a number of relict species to persist. The very situation of the plateau thus makes it a sort of bio-geographical crossroad.

Vegetation Analysis

Attock district is representative of Pothowar Plateau. Twenty study sites were selected in Attock district to cover the range of vegetation variation on the plateau (Fig. 1). Selection of these sites was based on repeated surveys. Plant species were inventoried in 5 × 2 m quadrates. Field sampling procedures involved the random placement of quadrates within each of the eight 25 × 50 m cells into which each study site was divided. On each site, presence or absence of all species was recorded from a sample of 24 quadrates (three per cell). Presence or absence of plant species was converted to frequencies and used to classify and ordinate both sites and species by the reciprocal averaging (RA) procedure of Hill and Gouch (1980). Rare species were eliminated from the analyses since these species can severely distort ordinations produced by RA (Hacker 1983; Dasti & Agnew 1994). Rare species occurred only in a single stand with frequencies of 1% or less. Detrended correspondence analysis (DCA) was selected as an appropriate ordination method based on gradient length and preliminary correspondence analyses (Jongman et al. 1995). The default options of the program DECORANA were used for the analyses (Causton 1988; Hill 1979). DCA axes 1 and 2 were used to interpret the data.

Species frequencies were clustered using the monothetic information statistic procedure incorporating the Spearman rank order dissimilarity coefficient (Causton 1988; Hill 1979). Scatter of classification groups were plotted on overlays of the ordination axes to assess the compatibility of the two methods of data simplification (Dargie & El Demerdash 1991; Dasti & Agnew 1994; Dasti & Malik 1998). The relationships between soil characters and DCA axes 1 and 2 were determined using Spearman rank correlation (Causton 1988).

Soil Analysis

Soil samples (0–10 cm depth) were taken from each site at three different points and mixed into a composite sample. Soil depth to 2 cm was sampled in the hard clays because the main root zone occurred within the top 2 cm layer. Sandy soils were sampled up to 10 cm depth because the top layer of soil was very mobile and the rooting zone was deeper. The samples were air-dried and passed through a 2 mm sieve. Three subsamples were drawn from this composite sample. Soil texture, water holding capacity, and soil moisture content was determined using standard methods (Hussain 1989; Richards 1954). Soil pH was recorded from a pH meter (HM–10K Digital, England), and conductivity was determined by CM-30 ET digital conductivity meter. Organic carbon was estimated following Jackson (1958).

The Duncan multiple range test was used to detect and compare any significant difference between the means of different communities at the 5% level of significance. The percent data obtained from particle size analyses were normalized by an arcsine transformation and subjected to analyses of variance between the communities for each variable.

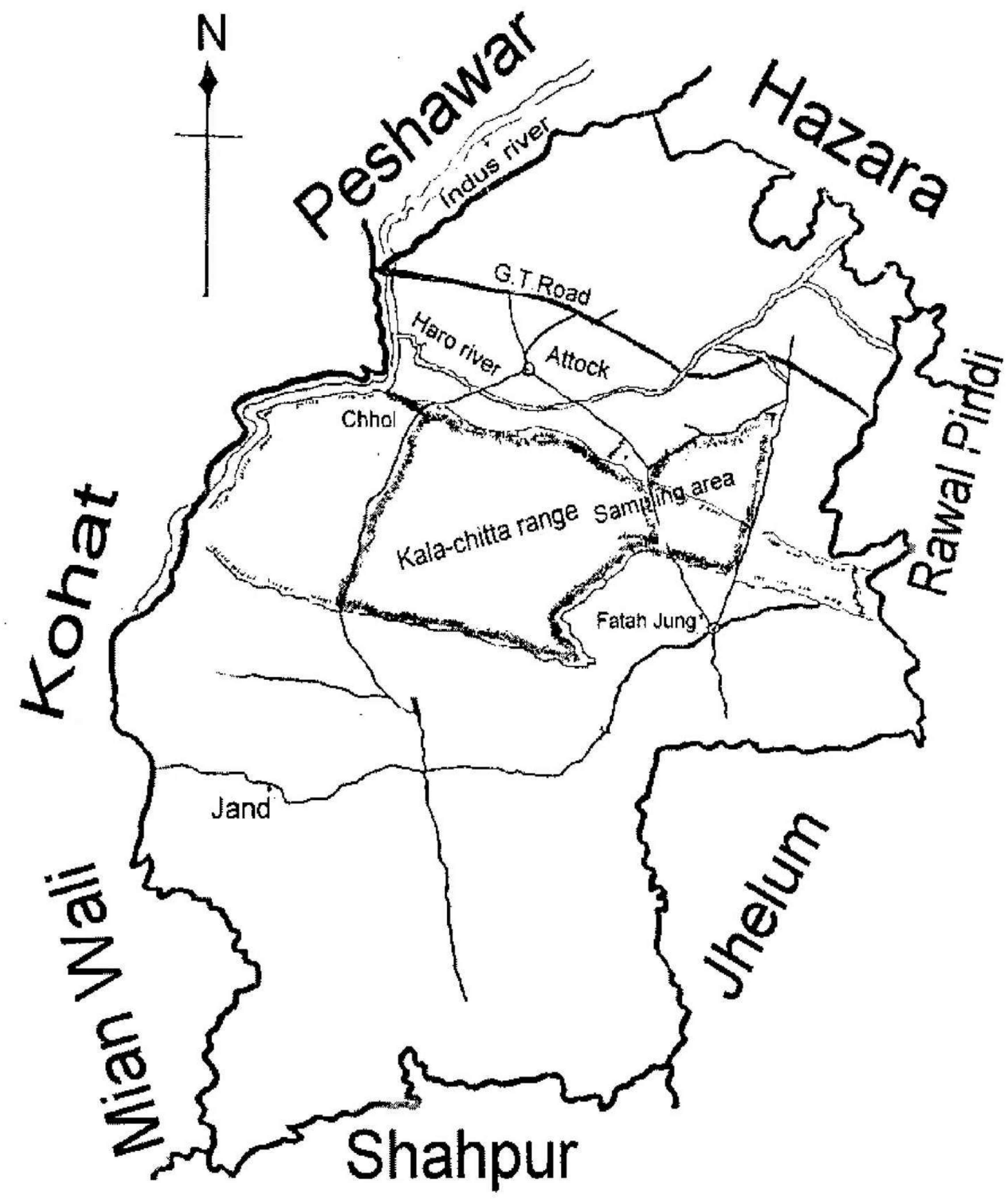

Fig. 1. Attock district map showing the sampling area on the Pothowar Plateau. The study region is marked with a broken boundary.

RESULTS

Classification

Five plant associations were recognized in the cluster analyses. The botanical composition of each association is presented in Table 1. These associations were delineated based on specifying three hierarchical levels (Fig. 2). The most noticeable feature indicated by this analysis was the separation of mountain-complex communities (Associations A-D) from the flat lowland community (Association E). The 55 samples of group E were separated from the other samples at the first level by *Chrysopogon aucheri*, and are characterized also by *Cyperus niveus* and *Dicanthium annulatum*. In the mountain-complex region, the limestone plateau communities (Associations A and B) were separated from those of the sandstone massif (Associations C and D) at level two by *Dodonaea viscosa*. As a result of three hierarchical levels four communities in the mountain complex were recognized:

1) Calcareous hilltops (Association A).
2) Interior rocky basins in the calcareous massif (Association B).
3) Sandstone massif (Association C).
4) Interior rocky basins on the sandstone massif (Association D).

The interior rocky basins on calcareous plateau (limestone strata) are characterized by *Olea cuspidata* that is altogether absent from such basins in sandstone strata. The enclosed basins with moderately to slightly

TABLE 1. Mean relative frequency values (%) of species in the 5 associations detected by normal cluster analyses.

Species	A	B	C	D	E
Acacia modesta Wall.	17.81	25.48	23.64	28.90	16.83
Acacia nilotica (L.) Debile	1.63	0.70	–	–	0.70
Anagalis arvensis L.	1.39	3.69	1.96	–	1.09
Asparagus gracilis Royle	0.40	–	–	–	–
Boerhaavia coccinea Mill.	–	2.37	–	–	3 .41
Capparis decidua (Forssk.) Edgew.	3.66	–	15.55	15.31	–
Carissa opaca Stapf ex Harines	0.64	–	–	–	3.69
Chrysopogon aucheri (Boiss.) Stapf.	–	–	–	–	49.60
Cymbopogon jawarancusa (Jones) Schult.	15.05	4.59	–	–	–
Cynodon dactylon (L.) Peris.	6.96	11.56	2.39	2.80	2.33
Cyperus niveus Retz.	–	–	–	–	7.37
Desmostachya bipinnata (L.) Stapf.	14.01	–	6.65	9.34	–
Dichanthium annulatum (Forssk.) Stapf.	–	–	–	–	5.55
Dodonaea viscosa (L.) Jacq.	23.34	12.01	–	–	19.26
Ehretia obtusifolia Hochst ex DC.	0.88	–	–	–	1.85
Eremopogon foveolatus (Del.) Stapf.	2.34	–	–	–	–
Erianthus griffithii (Munro) Hk. f.	29.87	5.84	0.80	–	1.94
Erodium cicutarium (L.) L'Herit ex Ait.	–	1.19	16.21	–	–
Evovulus alsinoides L.	–	0.97	–	–	3.62
Gnaphalium pulvinatum Del.	0.14	6.50	–	–	2.51
Grewia damine Gaertin	–	–	–	–	2.66
Grewia hirsuta Vahl	1.04	–	–	39.25	–
Grewia oppositifolia Roxb.	4.74	–	–	19.62	–
Grewia tenax (Forsk.) Aschers & Schweinf.	2.16	0.96	7.22	20.52	0.84
Grewia villosa Willd.	4.92	–	14.39	–	–
Gymnosporia royleana (Wall.) Lawson	9.75	21.24	21.08	8.09	18.67
Justicia peploides (Nees in Wall.) T. Anders	1.04	2.44	36.42	–	–
Linum strictum L.	7.30	–	–	–	4.47
Malcomia africana (L.) R.	0.25	0.92	4.28	19.62	1.12
Medicago laciniata (L.) Mill.	2.23	6.29	12.82	–	1.85
Melhania futteypoyensis Munro ex Mast	2.95	–	5.81	–	–
Myrsine africana L.	3.66	–	5.32	0.86	0.35
Olea cuspidata Wall. ex DC.	20.86	15.32	4.04	–	27.32
Oxalis corniculata L.	–	5.12	0.80	–	1.93
Periploca aphylla Dcne.	1.94	–	5.63	2.89	–
Plantago ciliata Desf.	–	2.37	–	–	1.93
Prosopis juliflora Swartz	0.09	7.37	12.64	–	–
Reptonia buxifolia Dcne.	7.23	7.52	–	–	–
Rhamnus pentapomica Parker	1.58	–	4.63	20.53	–
Rhazya stricta Dcne.	0.09	3.18	–	6.06	–
Sageretia theezans (L.) Brongn	–	–	–	–	6.24
Taraxacum officinale Wigg.	0.43	2.80	–	–	0.99
Tetrapogon villosus Desf.	–	–	–	–	2.61
Trachynia distachya (L.) Link	4.97	32.52	–	1.06	–
Ziziphus jujuba Mill.	3.69	5.93	–	–	–
Ziziphus nummularia (Brum. f.) Wight & Arn.	1.77	2.71	0.23	16.47	2.99

impeded run-off are dominated by various species of *Grewia*. Further subdivisions at lower information gains were regarded as minor variants, and were not considered. The vegetation communities are briefly described below in the context of the major discriminating species. For this purpose the area has been subdivided into five broad regions based on geomorphology.

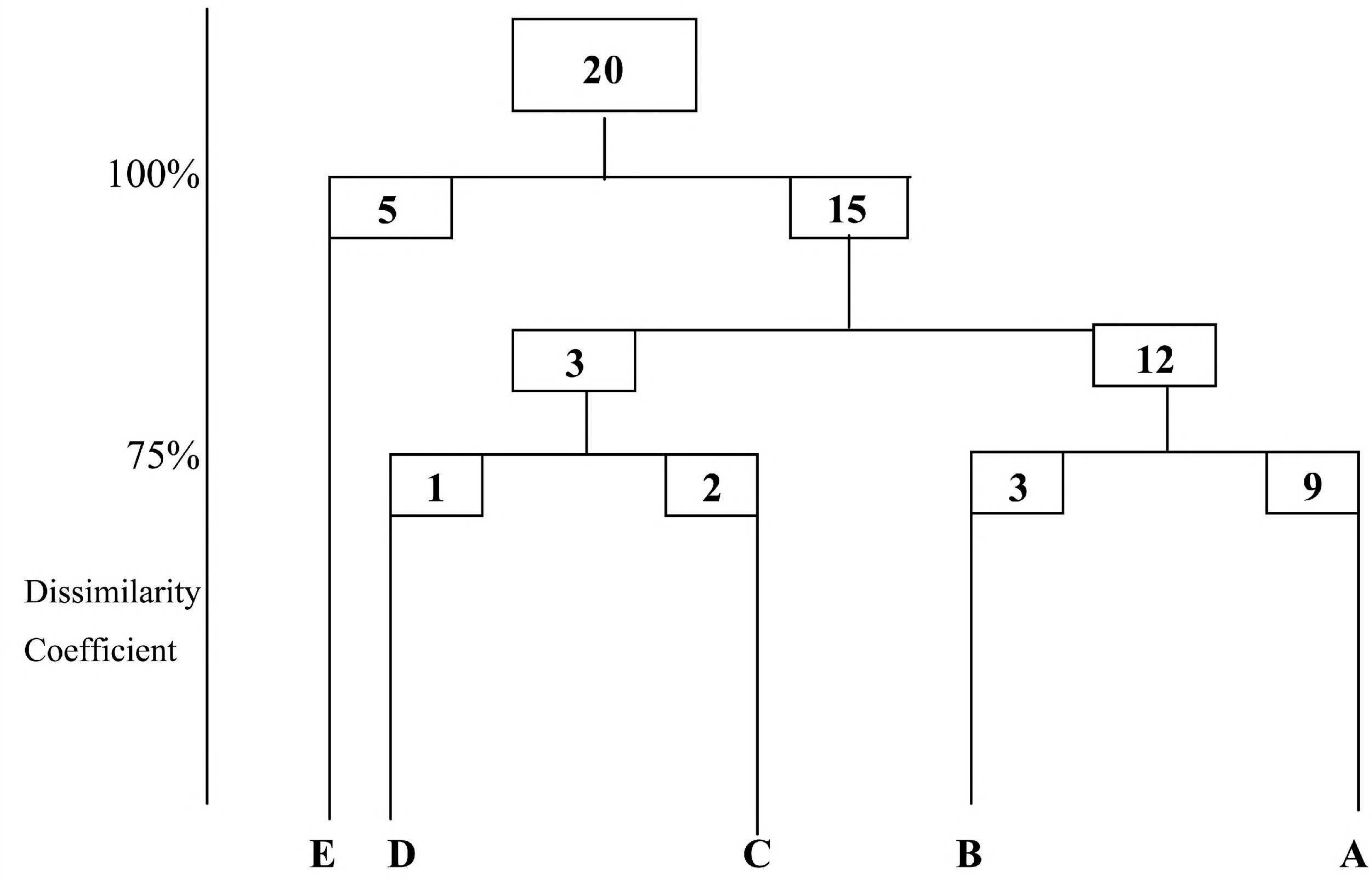

Fig. 2. Dendrogram for the cluster analyses of sampling sites, with 20 sites divided into five groups. The number of sites in each plant association is given in boxes.

1. Mountain-Complex Plant Communities

The mountain-complex communities represent the vast extensive rocky hillocks and scarps with a thin veneer of sediments. Skeletal soils of these habitats have no clear-cut profile. However, some minor rocky hollows (enclosed basins) strewn with stony material exist in hills and scarps where run-off accumulates during summer.

1.1. Limestone massif: ***Erianthus griffithii*** *community–Association A.*—This association dominates extensive areas in the limestone plateau and represents the characteristic vegetation of skeletal soils with no clear-cut profile. Such soils develop generally on calcareous parent material and support xerophytic species. *Acacia modesta, Dodonaea viscosa, Erianthus griffithii, Gymnosporia royleana,* and *Olea cuspidata* are the major species of this type of vegetation. The dominance of *E. griffithii*, along with other perennial grass such as *Cymbopogon jwarancosa* and *Desmostachya bipinnata*, gives this community a superficial resemblance to gramineous steppe.

1.2. Enclosed basins in calcareous massif: ***Trachynia distachya*** *community–Association B.*—This association represents the vegetation of depressions or hollows strewn with stony material with a lime incrustation. This association is dominated by *Acacia modesta, Dodonaea viscosa, Gymnosporia royleana* and *Olea cuspidate.* Compared with the former association, the contribution of *Cymbopogon jwarancosa, Eremopogon foveolatus* and *Erianthus griffithii* decreased remarkably. This association is marked by high average frequency of *Trachynia distachya* and a ground cover of *Cynodon dactylon, Malcomia africana,* and *Plantago ciliata.*

1.3. Enclosed basins in sandstone massif: ***Justicia peploides****–Association C.*—Association C includes the stands belonging to the northern inter-mountain depressions in sandstone strata. This association is distinctive because of the high dominance of *Acacia modesta, Capparis decidua, Erodium cicutarium, Grewia villosa, Gymnosporia royleana, Justicia peploides* and *Prosopis juliflora* and a few plants of *Olea cuspidate*

1.4. Sandstone plateau: ***Acacia modesta****–Association D.*—This association represents the southern slope of sandstone strata (Kala-Chitta range). The general vegetation is of the xeromorphic woodland type; the chief tree and shrub species are *Acacia modesta, Capparis decidua, Grewia hirsuta, G. oppositifolia, G. tenax, Rhamnus pentapomica,* and *Ziziphus nummularia.* The herbaceous vegetation is extremely short and includes annuals like *Malcomea africana* that appears during the short period of the rainy seasons.

2. Lowlands or playes (Wadi beds) communities

Lowlands receive run-off during rains and become dry thereafter. Wadi soils are formed from alluvial sediments carried down the slopes by run-off water. They are characterized by their heavier texture, high water-holding capacity, deeper profile and slightly to poor drainage. The alluvial playes are dominated by shrubs of *Olea cuspidata* associated with *Chrysopogon aucheri* (Association E) in more favorable habitats (oases), like runoff-fed depressions and runnels. Beside the dominant species (*Cyperus niveus* and *Dichanthium annulatum*), *Acacia modesta, Dodonaea viscosa,* and *Gymnosporia royleana* are common associates. The woody components of this association have large ranges and are generally found in oases as well as the plateau and scarps under the most arid conditions.

Gradient Analysis

Site and species ordination in the plane of first two axes are presented in Figures 3 and 4. The first DCA axis of the normal data set had an eigenvalue of 0.392 (13% of the variance explained). The eigenvalue for the second axis was 0.207 (8% of variance explained). Further axes each explained less than 7% of total variances.

Site ordination (Fig. 3) reveals a marked relationship between the first axis and the soil factors. There was a highly significant correlation ($P < 0.01$) between the sample scores along DCA axis 1 and the components of soil texture (sand, silt and clay) and moisture, r^2 values exceeded 0.4. Regarding axis 2, r^2 values of these edaphic factors were considerably low (< 0.03). Besides the soil physical characters, soil pH showed a significant positive correlation ($P<0.05$) with DCA axis 1, but not with axis 2. The availability of organic matter in the sample plots showed a significant correlation with both DCA axes (Table 2). In addition to these factors, the ordination axes (1 and 2) appeared markedly influenced by topography, redistribution of rainwater and soil depth. It is evident from Figure 3 that sites of the Wadi-beds (16-20, stands belonging to Association E) are clearly grouped at one end (high score) and those of mountain complex (1-15 sites belonging to Associations A-D) on the other end (low score) of DCA axis 1. However, among the mountain complex, several sites are separated from the others suggesting a degree of floral diversity within this group. Site 15 is strongly separated from rest of the sites suggesting again the operation of site-specific factors. Sites of the enclosed basins (2, 3 and 12) that collect the run-off water occupy an intermediate position along axis 1 reflecting the fair conditions of water and soil availability for plant growth. The distribution of the species along DCA axes 1 and 2 is presented in Figure 4. Several species had configurations similar to that evident for sites. However, some species do not follow the site distribution, suggesting that they are largely unaffected by the underlying topographic or edaphic factors.

Comparison of the site and species ordinations reveals that the separation of Wadi sites (16-20) as a distinct group at the resource-rich end of the gradient is due to the relative abundance of *Chrysopogon aucheri* and the presence of *Cyperus niveus, Dicanthium annulatum, Grewia damine,* and *Sageretia theezans*. These species are virtually absent from the plateau sites. The ordination positions of *Grewia tenax, Justicia peploides, Medicago laciniata, Prosopis juliflora,* and *Trachynia distachya* suggest that these species are characteristic of moderately xeric habitats. Both *Cymbopogon jawarrancusa* and *Desmostachya bipinnata* have maximum frequencies on the limestone massif. *Capparis decidua* defines the most xeric end of the gradient, while *Grewia hirsuta* and *Rhamnus pentapomica* display marked peaks in frequency on the eroded sandstone sites.

The remaining species occupy ordination positions that suggest a lack of any association to the site configuration along the gradient. These are identified as a group within the marked boundary of Figure 4. The distributions of *Acacia modesta, Dodonaea viscosa, Erianthus griffithii, Gymnosporia royleana, Olea caspidata,* and *Reptonia buxifolia* are particularly noteworthy. Among these species *G. royleana* and *O. cuspidata* show marked increases in frequency from plateau to lowland communities (Table 1). While *A. modesta* is able to

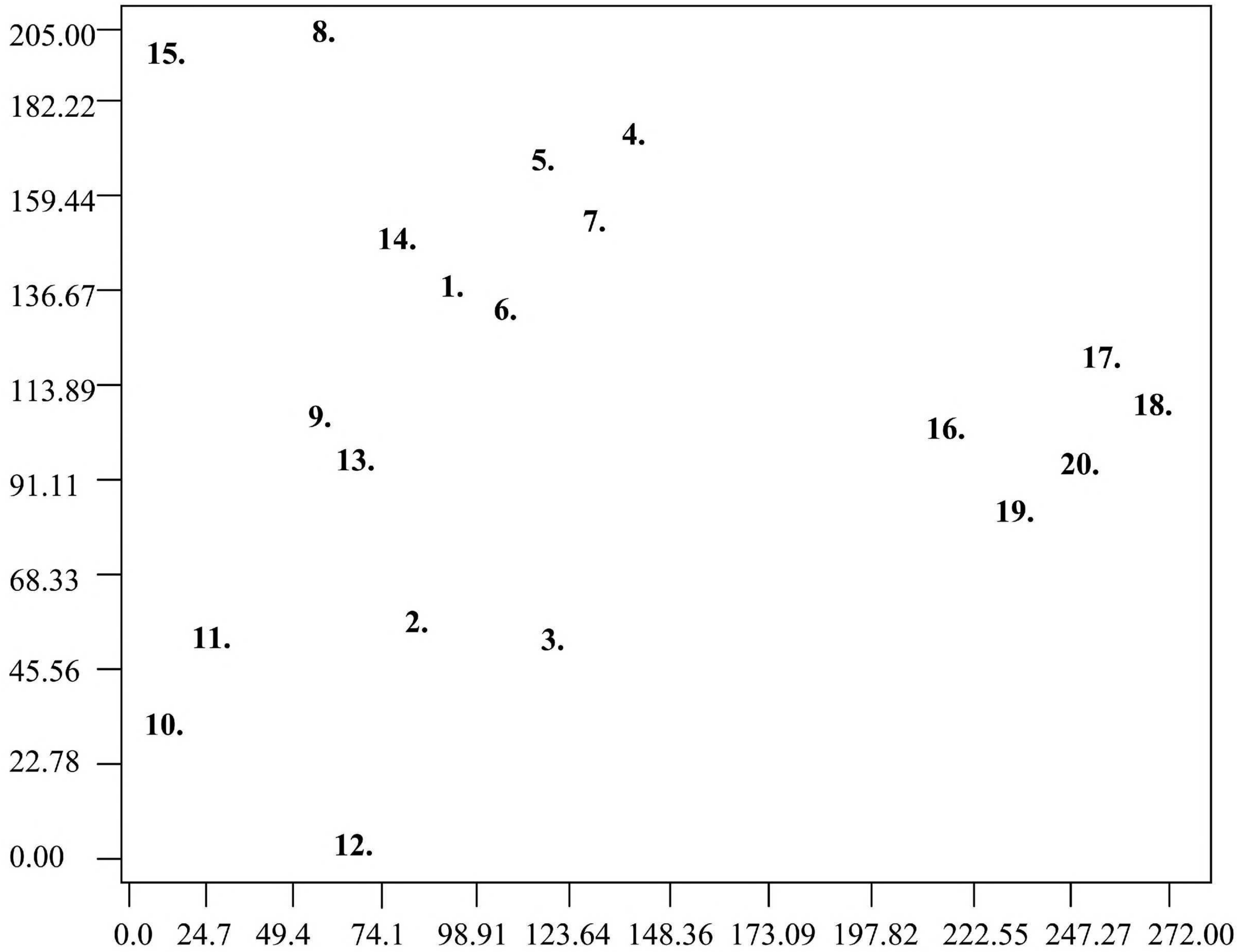

Fig. 3. Sites biplot of detrended correspondence analysis (DCA) axes 1 and 2 for the qualitative vegetation data obtained from Pothowar Plateau. The distributions of 20 sites along the DCA axes are numbered.

maintain relatively constant frequencies in all the sites, *D. viscosa, E. griffithii,* and *R. buxifolia* showed a pattern of increasing frequency of occurrence when extended to limestone plateau sites. In fact these species are absent from sandstone massif.

DISCUSSION

Plant assemblage and geomorphology

The results indicate that the landscape, nature of the rock and redistribution of rainfall water by run-off are the main sources of spatial variation in the study area. These geomorphological factors determine the boundaries and the composition of the plant communities. The species *Chrysopogon aucheri, Cyperus niveus, Dicanthium annulatum, Grewia damine,* and *Sageretia theezans* in Association E (Table 1) are most common in the flat or rolling lowlands that receive sufficient runoff water, and virtually absent from plateau sites. The species *Boerhaavia coccinea, Carissa opaca, Ehretia obtusifolia, Evovulus alsinoides,* and *Olea caspidata* reached maximum abundance in valley bottom sites and showed declining frequency of occurrence when extended into the plant communities on shallower soils of plateau sites (A-D). This pattern of distribution provides strong circumstantial evidence that dip and scarp slopes (topography) determine the differences in vegetation types through the distribution of run-off generated by rainwater. Depth and moisture of the soil again are important factors that exert influence on plant assemblages. On scarp slopes, the soil is shallow and quickly dries out representing the more xeric habitat as indicated by DCA.

In upper plateau sites, the boundaries and composition of plant communities are determined by a

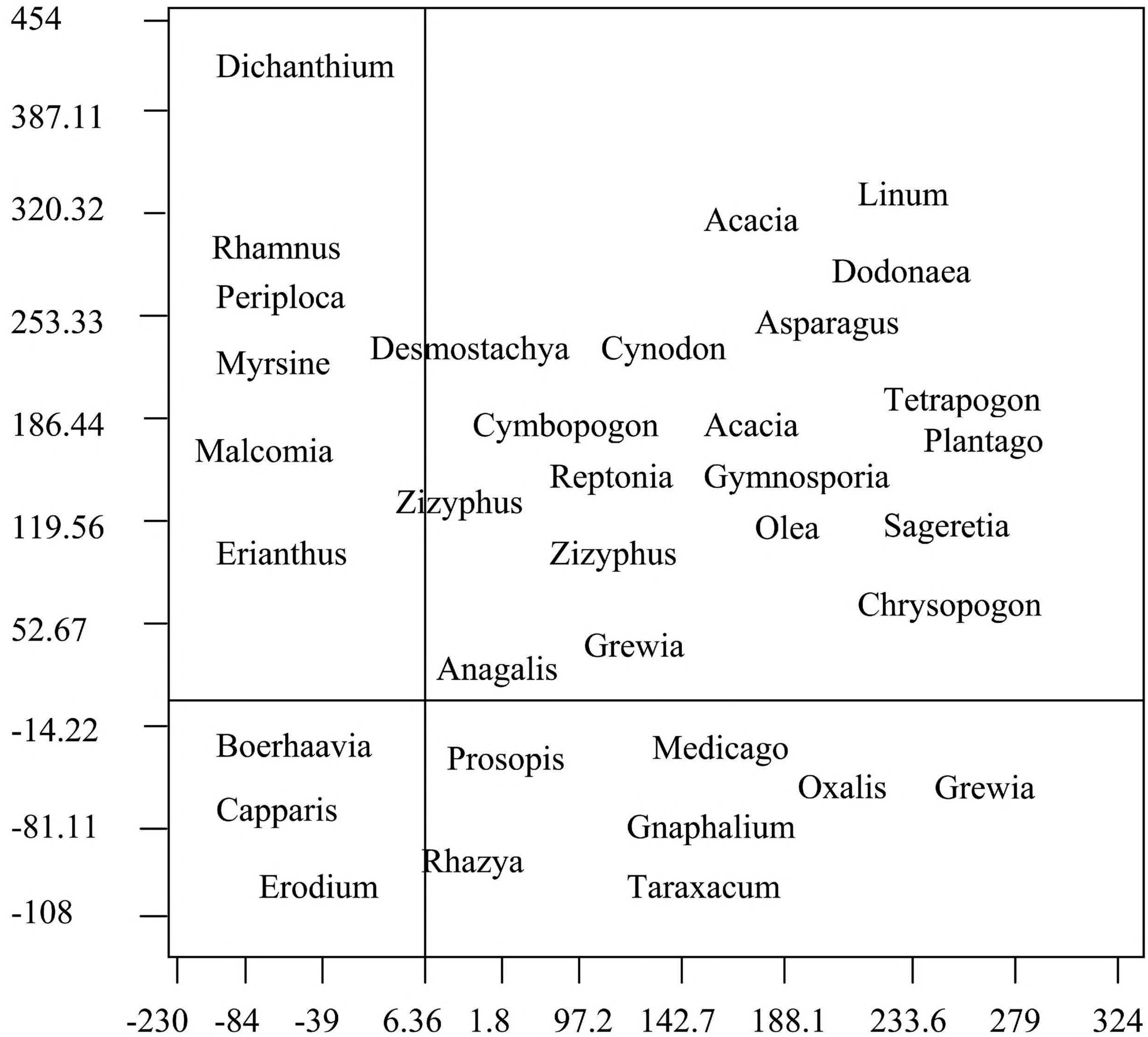

Fig. 4. Results of detrended correspondence analysis (DCA) for the distribution of the 46 species included in the vegetation analyses.

complex of factors including moisture, geology, soil and adjacent topography (Champion et al. 1960, 1965). The most influential factor in distribution of the vegetation appeared to be the geological substrate. For example, the species *Acacia nilotica, Asparagus gracilis, Cymbopogon jawarencusa, Dodonaea viscosa, Erodium cicutarium, Eremopogon foveolatus, Erianthus griffithii, Gnaphalium pulvinatum, Olea caspidata, Prosopis juliflora, Reptonea buxifolia,* and *Ziziphus jujuba* are associated with limestone strata (Association A). These species are altogether absent from the eroded sandstone plant communities (Association D). A fairly high available calcium status is possibly associated with the frequent occurrence of these species. Such species may be considered as lime tolerant (Hussain 1969). Besides these differences in species composition, species abundance also varies between the lime and sandstone sediments (Table 1). The majority of the plant species that are distributed over calcareous or non-calcareous rocks of the mountain complex showed a pattern of increasing frequency of occurrence when extended to sandstone plateau. This trend is common in *Acacia modesta, Capparis decidua, Grewia hirsuta, G. oppositifolia, G. tenax, Periploca aphylla, Rhamnus pentapomica, Rhazia stricta,* and *Ziziphus nummularia.*

Enclosed depressions in the limestone plateau form a marked transitional zone where the soil is mixed with rock fragments. Clay minerals of limestone-derived soils are largely inherited from the parent material.

Table 2. Spearman rank correlation coefficients between the detrended correspondence analysis (DCA) first and second axes.

Soil Parameters	Axes 1	Axes 2
Sand	-0.609**	0.089
Silt	-0.618**	0.161
Clay	0.744***	-0.176
EC (s cm^{-1})	0.313	0.393
pH	-0.543*	0.041
Organic matter	-0.407*	-0.456*
Water holding capacity	0.075	-0.619**
Moisture content	0.425*	-0.115

Level of significance: * P≤0.05, ** P≤ 0.01, *** P≤0.001.

The soils in the enclosed depressions remain exposed to continuous leaching, physical erosion and physico-chemical changes without any rule by which a precise pattern of plant assemblage can be determined. However, *Acacia modesta, Gymnosporia royleana, Prosopis juliflora, Trachynia distachya* and other species are more frequent in depressions over limestone massifs while *Acacia modesta, Capparis decidua, Erodium cicutarium, Justicia peploides,* and *Prosopis juliflora* are frequent on sandstone massif (Association C). This may be interpreted as the variation in floristic composition on these strata that commonly reflects variations in the substrate which in-turn depends on the nature of the parent materials from which the soil is derived.

The vegetation environmental correlation

Apart from the fact that the landscape variables are indeed relevant for explaining the main vegetation types, the correspondence between the results of cluster analyses and DCA planes permit a direct interpretation of scores of stand data in DCA plane in relation to soil variables. The five associations produced by cluster analysis are plotted on first two axes as a scattered diagram (Fig. 5). The ordination axes may represent in some way the major substrate influences, which affects the stands in these data, and have been used as the plant and soil characteristics of the associations to discuss the most significant features of the environment (Table 2).

The importance of water holding capacity and organic matter as the environmental factors affecting plant species associations is not surprising, but has close relationship with water absorption and its retention. The present analyses and assessment of pattern and zonation along the first ordination axis suggest that the most important environmental gradient and boundaries across the landscape are associated with organic matter. The distribution of species along ordination axis 2 is significantly related not only to organic matter, but also to water holding capacity. However, it is difficult to assess the relative importance of these factors, but consistent negative interaction terms between these factors suggest that some combined effect is important. The reasons for these correlation must be hydrological, particularly the pattern of run-off generation and redistribution of organic matter of the study area, and probably are common to many arid mountain terrains (Dasti & Malik 1998).

Vegetation is a complex collection of substrate specialists and generalists. It may be concluded that both classification and ordination are able to delimit the plant associations according to their environments. Topographic heterogeneity at the local scale also is an important factor that governs the community structure in plateau habitat. The complex gradients in edaphic conditions associated with topography provide an opportunity to conduct further research, both in the laboratory and the field.

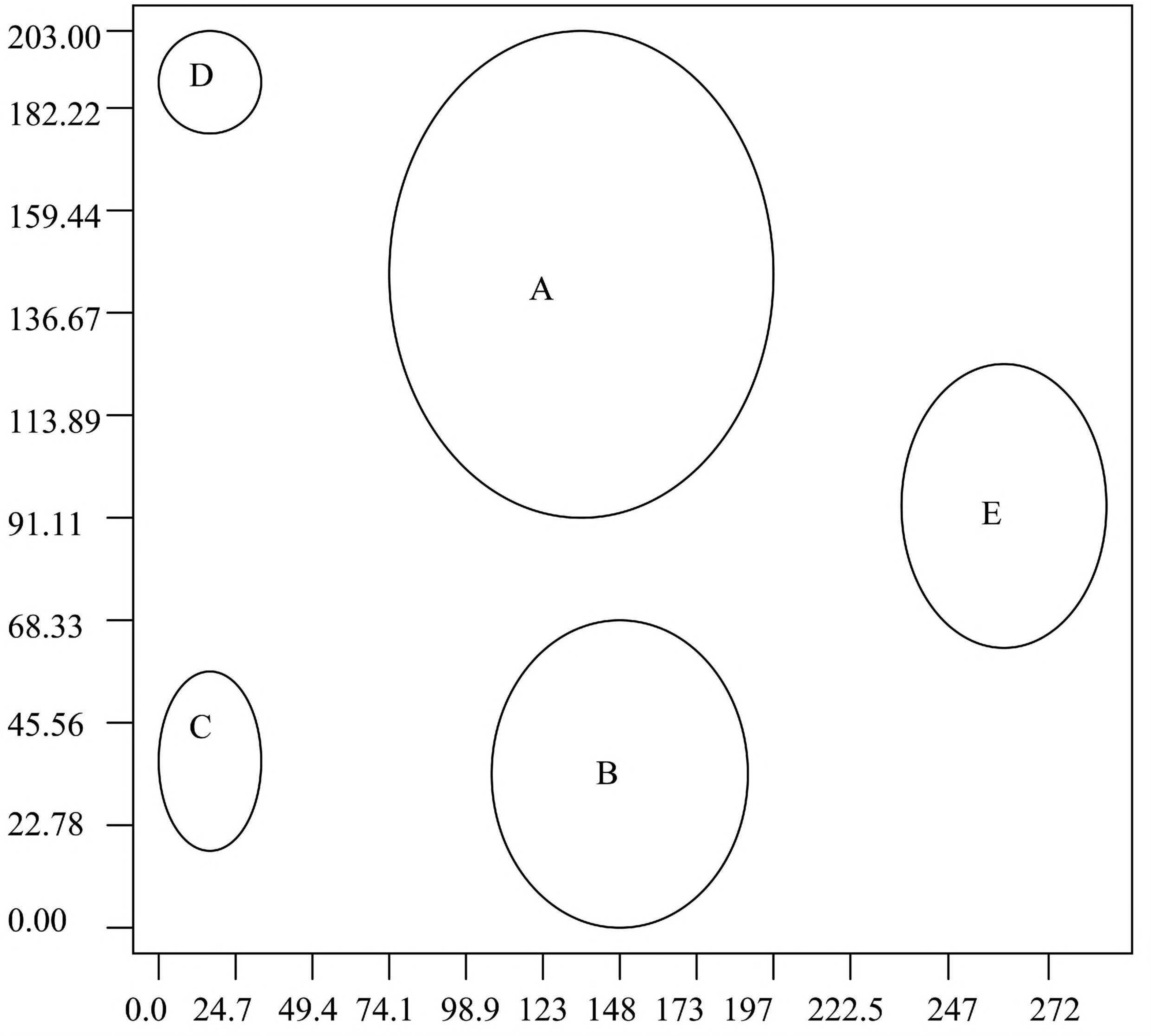

Fig. 5. Results of detrended correspondence ordination of the sites grouped by the associations produced by cluster analyses.

ACKNOWLEDGMENTS

The manuscript was prepared when Mohammad Athar (Tariq) was a visiting professor at the Institute of Pure and Applied Biology, Bahauddin Zakariya University, Multan under the foreign faculty hiring program of the Higher Education Commission, Islamabad. The authors are grateful to Joseph H. Kirkbride, Jr. and two anonymous reviewers for providing valuable suggestions for improving the manuscript.

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